Low-power digital microwave radiometer technologies

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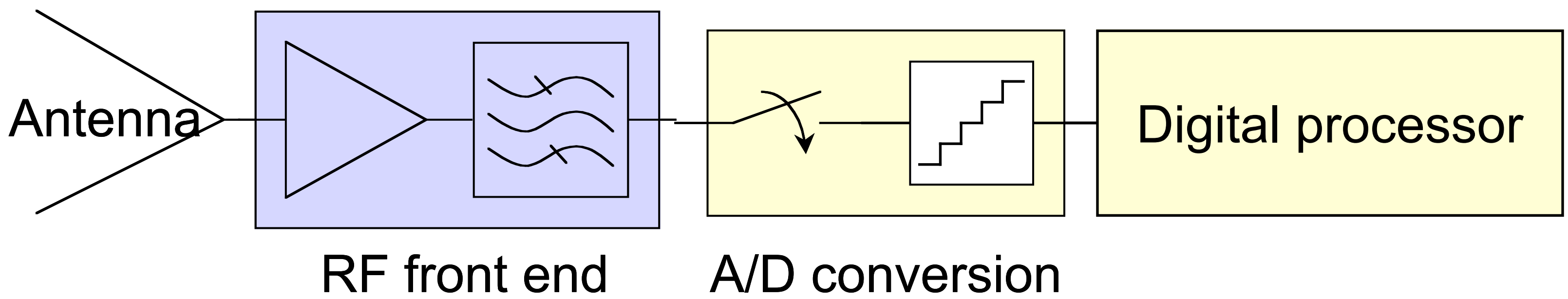
Outline

- Background
  - Digital radiometer
  - Polarimeters and calibration
- Bench-top radiometer
  - Dual-channel receiver
  - Digital correlator
  - Correlated noise source
  - Waveguide noise standard
- SiGe RF-ADC
- Discussion

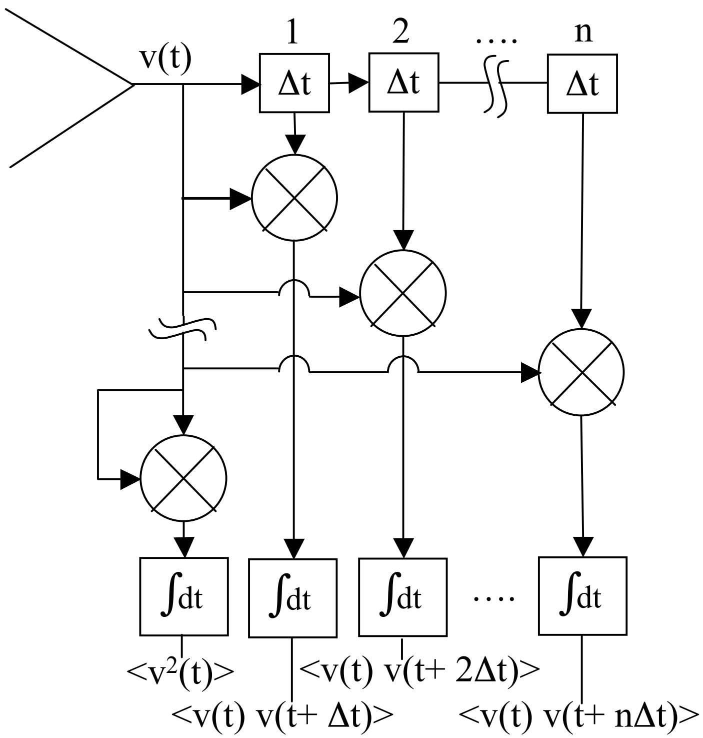
Background

- Digital radiometry - move ADC before detector
- Weinreb - autocorrelation spectrometer (1961)
- Types of digital radiometers
  - Correlation based
    - Imaging – interferometer
    - Spectrometer – autocorrelator
    - Polarimeter – cross-correlator
  - DSP based
    - Imaging phased array
    - Spectrometer – filter bank
  - RFI mitigation

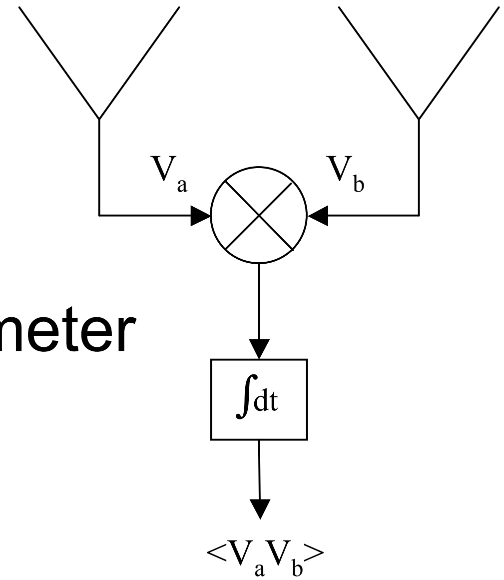


Digital Radiometer Types

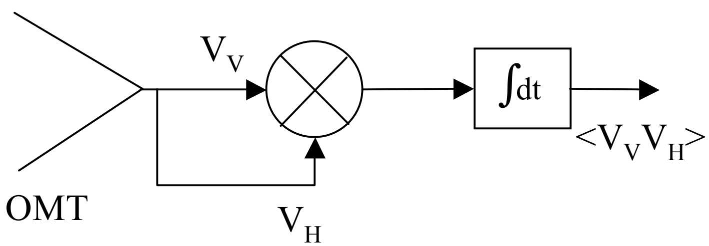
Spectrometer



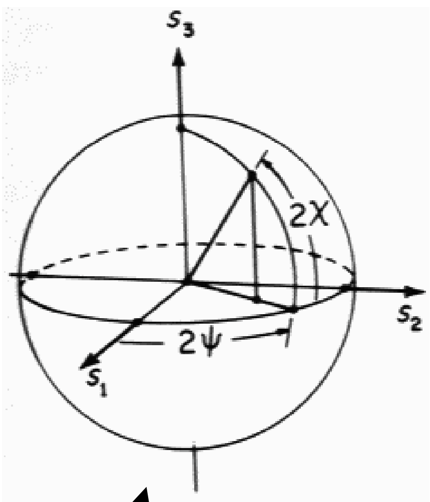
Interferometer



Polarimeter



Microwave Polarimetry

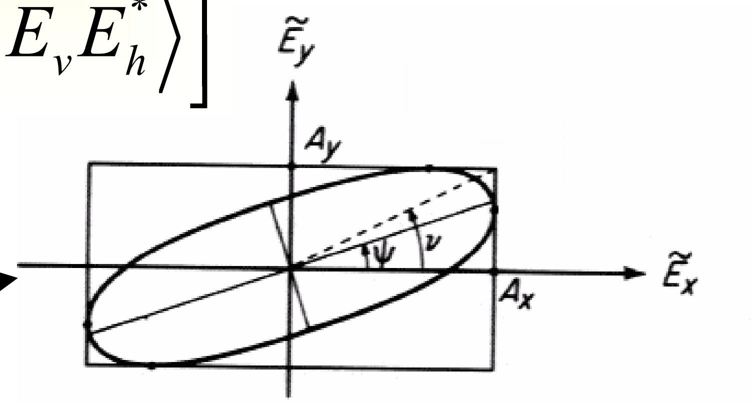


Poincare Sphere

$$\begin{bmatrix} T_v \\ T_h \\ T_U \\ T_V \end{bmatrix} = \frac{\text{ë}^2}{\text{ç}kB} \begin{bmatrix} \left\langle |E_v|^2 \right\rangle \\ \left\langle |E_h|^2 \right\rangle \\ 2\,\mathrm{Re}\left\langle E_v E_h^* \right\rangle \\ 2\,\mathrm{Im}\left\langle E_v E_h^* \right\rangle \end{bmatrix}$$

Stokes Vector

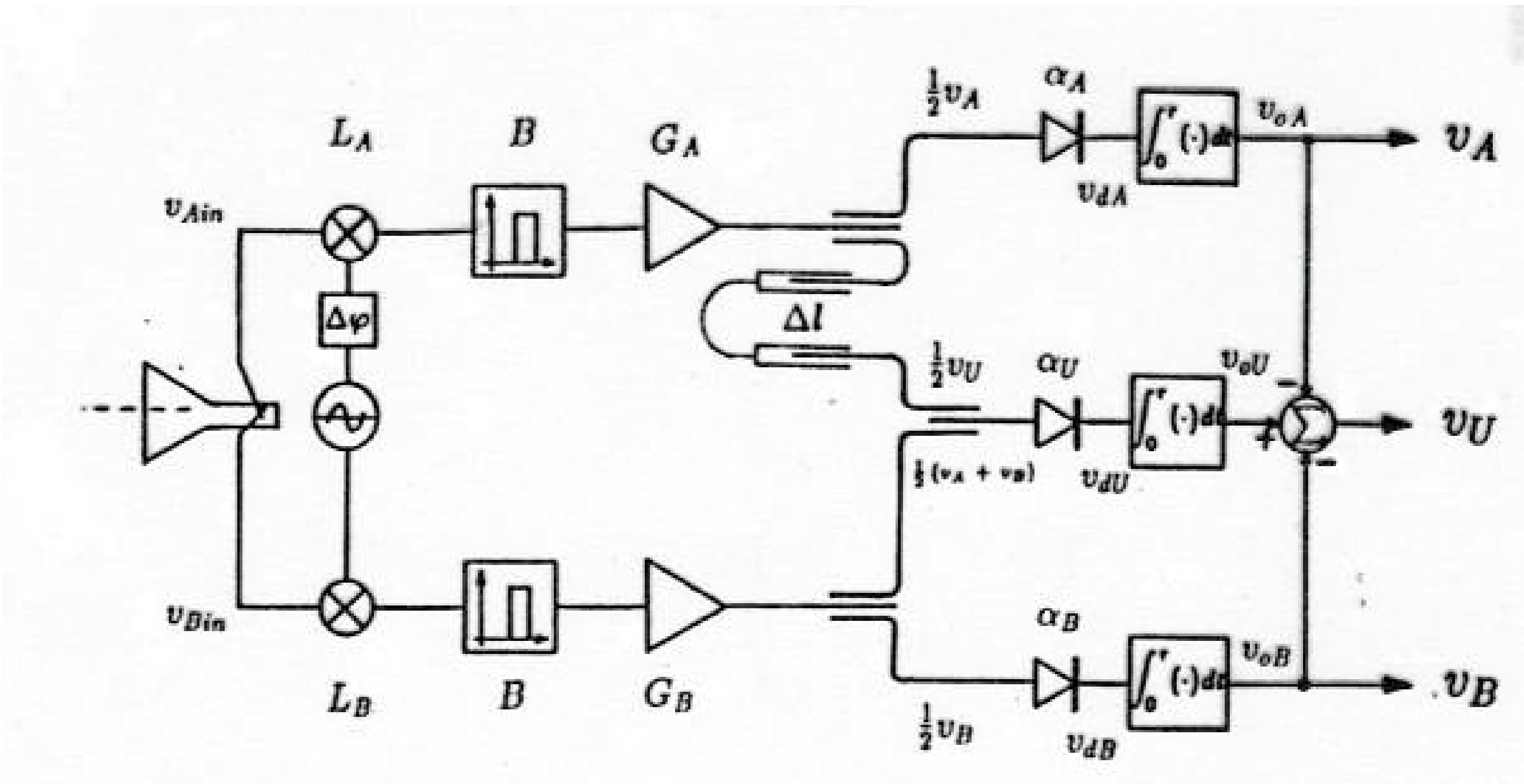
Polarization Ellipse



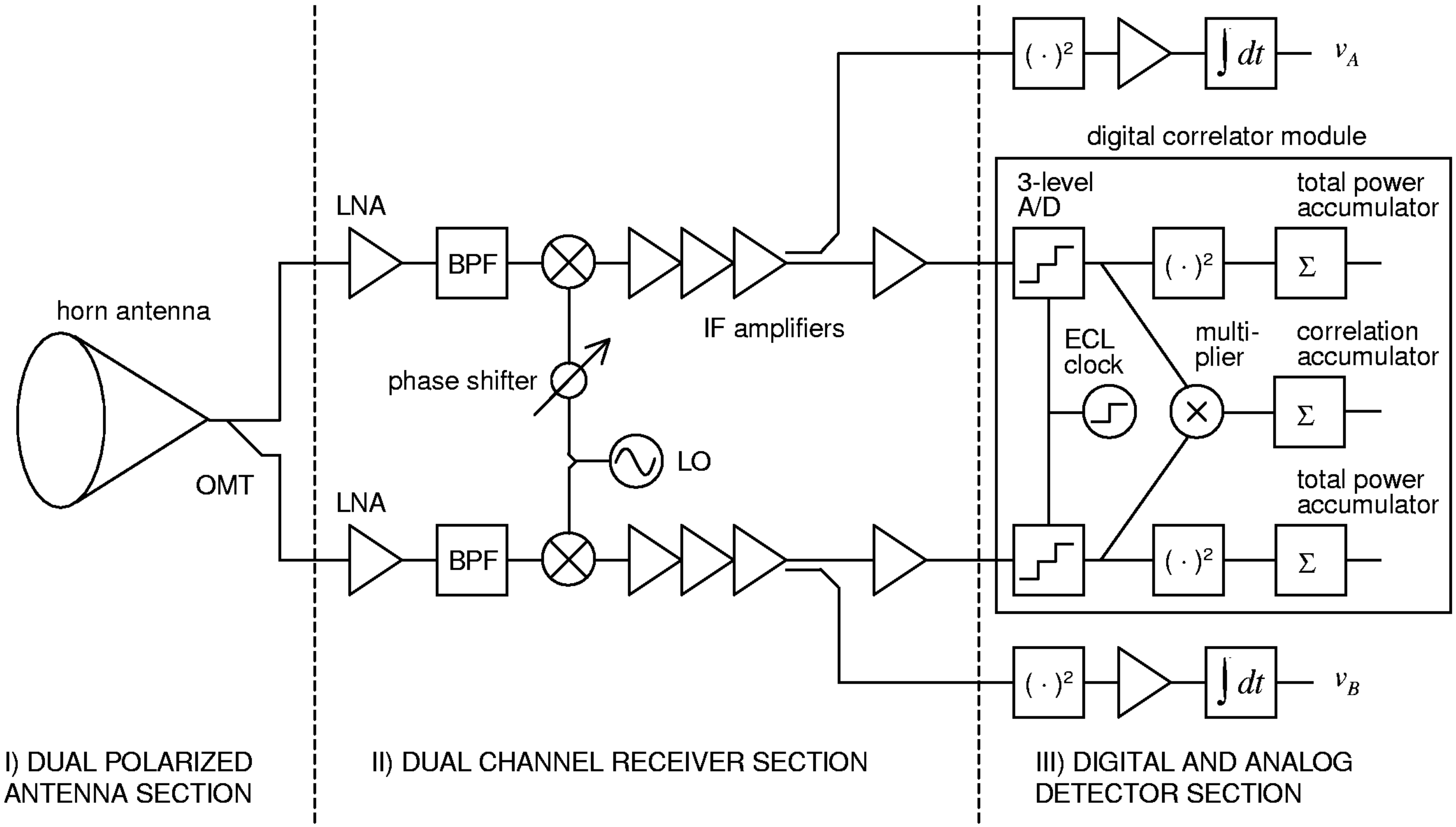
Why Polarimetry?

- Good place to study digital radiometers
  - Conventional real aperture
  - One complex correlation
  - Challenging: large bandwidth and low power
- Timely
  - COREOLIS/WINDSAT NPOESS/CMIS
  - AQUARIUS HYDROS SMOS/MIRAS
- Types
  - Incoherent, e.g. WINDSAT
  - Coherent (Adding and Multiplying), e.g. AQUARIUS

Coherent polarimeter 1. (adding type)



Coherent polarimeter 2. (multiplying type)



Calibration

- General system equation

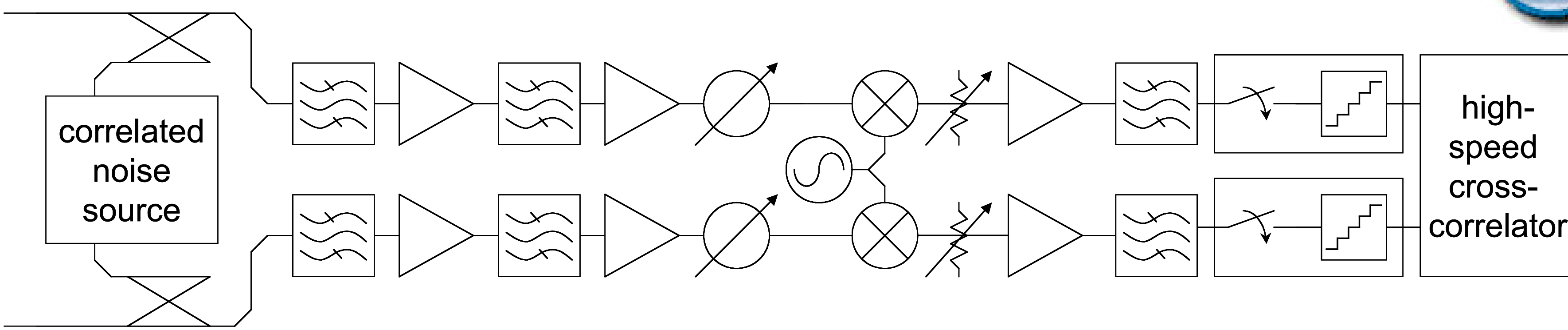
$$\begin{bmatrix} v_a \\ v_b \\ v_U \end{bmatrix} = \begin{bmatrix} G_{aa} & G_{ab} & G_{aU} \\ G_{ba} & G_{bb} & G_{bU} \\ G_{Ua} & G_{Ub} & G_{UU} \end{bmatrix} \begin{bmatrix} T_{A,a} \\ T_{A,b} \\ T_{A,U} \end{bmatrix} + \begin{bmatrix} o_a \\ o_b \\ o_U \end{bmatrix}$$

- Correlating polarimeter

$$\begin{bmatrix} v_a \\ v_b \\ v_U \end{bmatrix} = \begin{bmatrix} G_{aa} & 0 & 0 \\ 0 & G_{bb} & 0 \\ 0 & 0 & G_{UU} \end{bmatrix} \begin{bmatrix} T_{A,a} \\ T_{A,b} \\ T_{A,U} \end{bmatrix} + \begin{bmatrix} o_a \\ o_b \\ o_U \end{bmatrix}$$

- Need correlator gain

Our system

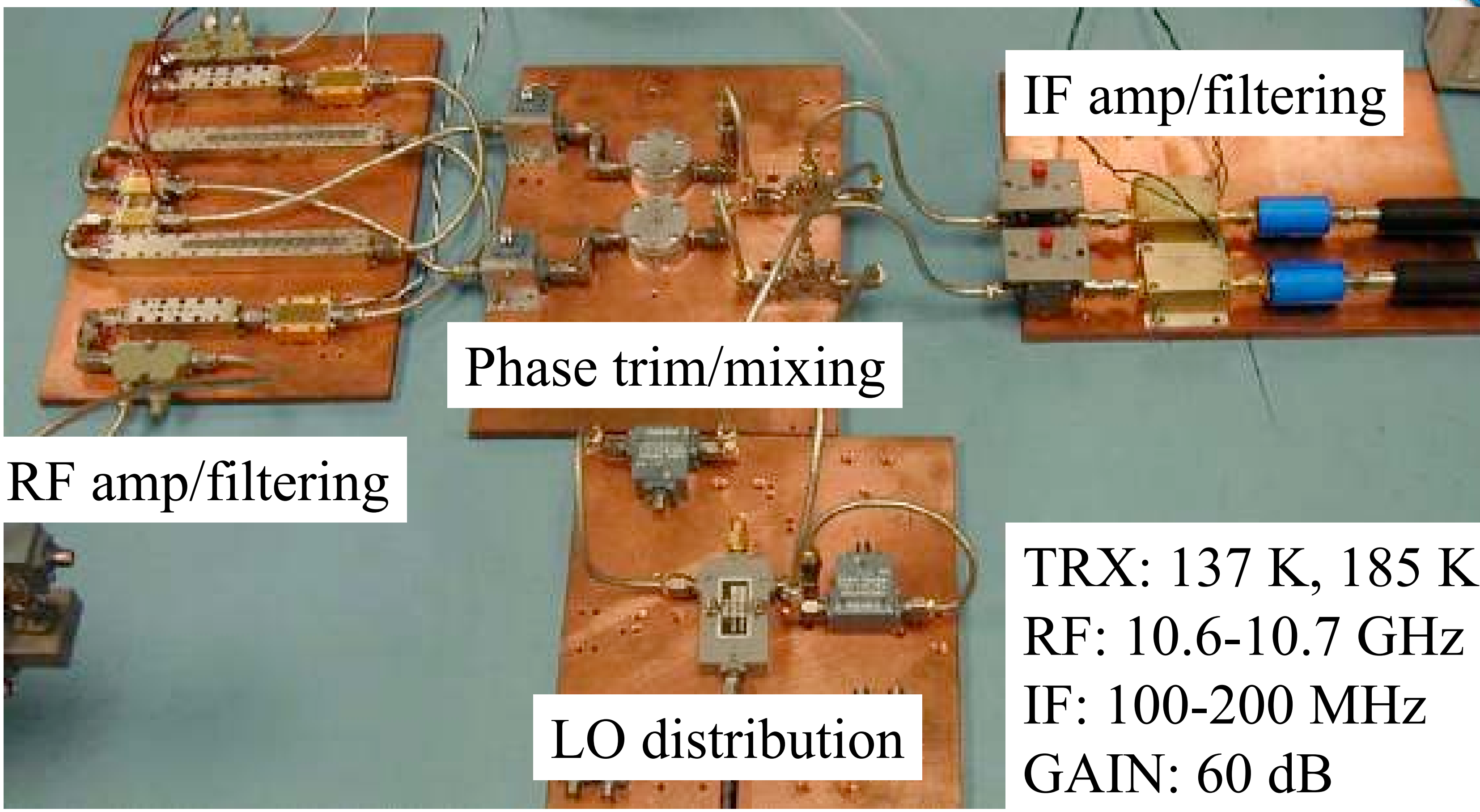


- Calibration: “polarimetric efficiency”

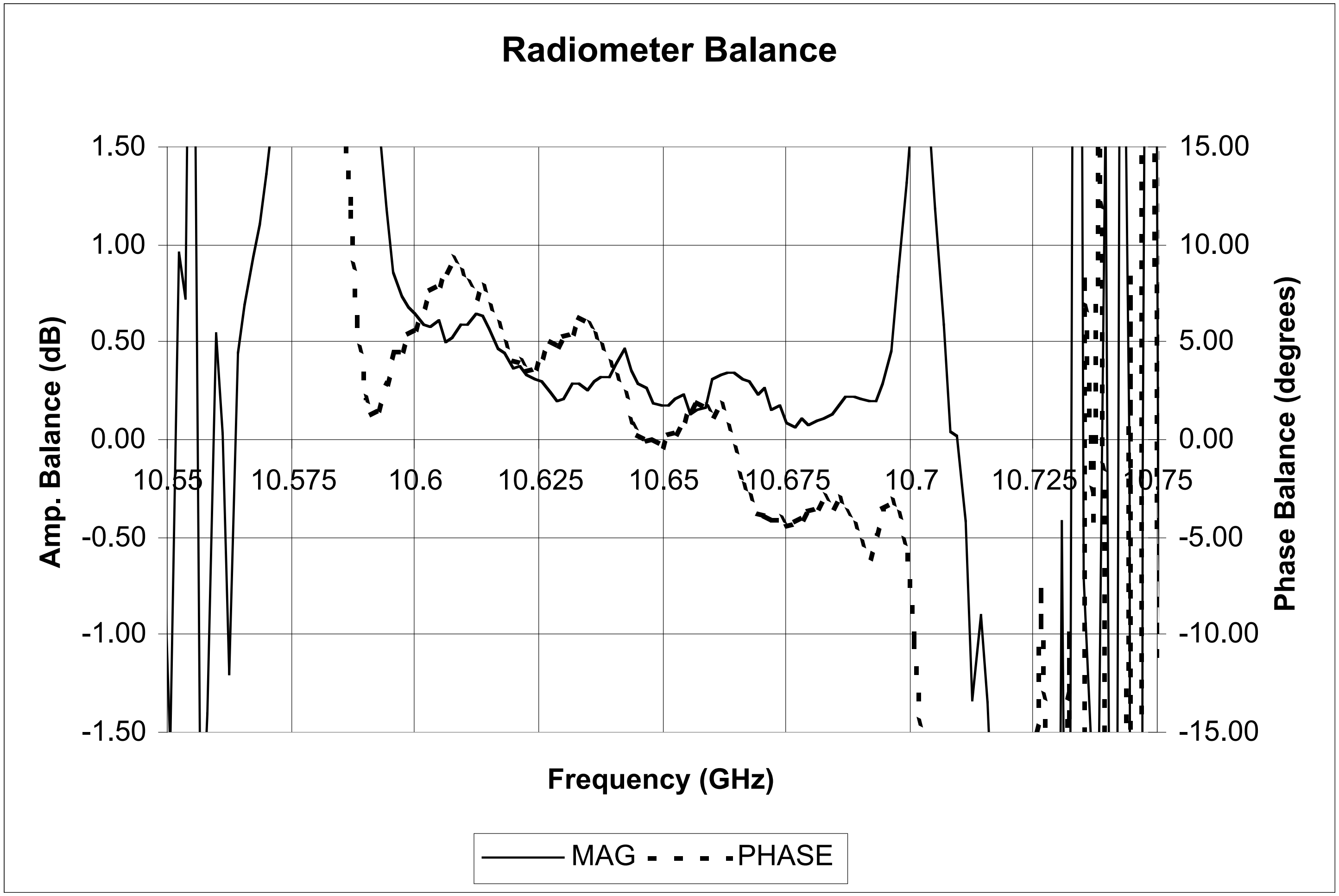
$$\eta = \frac{\int_{-\infty}^{+\infty} H_A(f)\, H_B^*(f)\, df}{\left(\int_{-\infty}^{+\infty} |H_A(f)|^2\, df \cdot \int_{-\infty}^{+\infty} |H_B(f)|^2\, df \right)^{1/2}}$$

- Correlated noise source from radio astronomy

Dual-channel Receiver



TRX: 137 K, 185 K
RF: 10.6-10.7 GHz
IF: 100-200 MHz
GAIN: 60 dB



$0.18^{o} \pm 7.5^{o}$

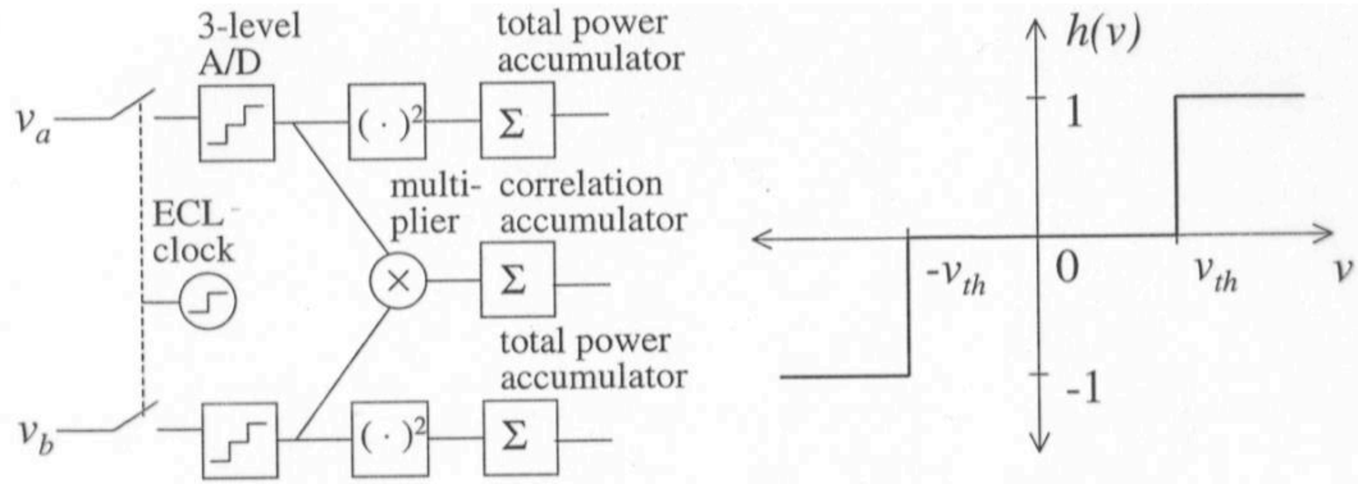
0.1 dB +1.5 dB/-0 dB

$\eta = 0.991 \angle 1.1^{o}$

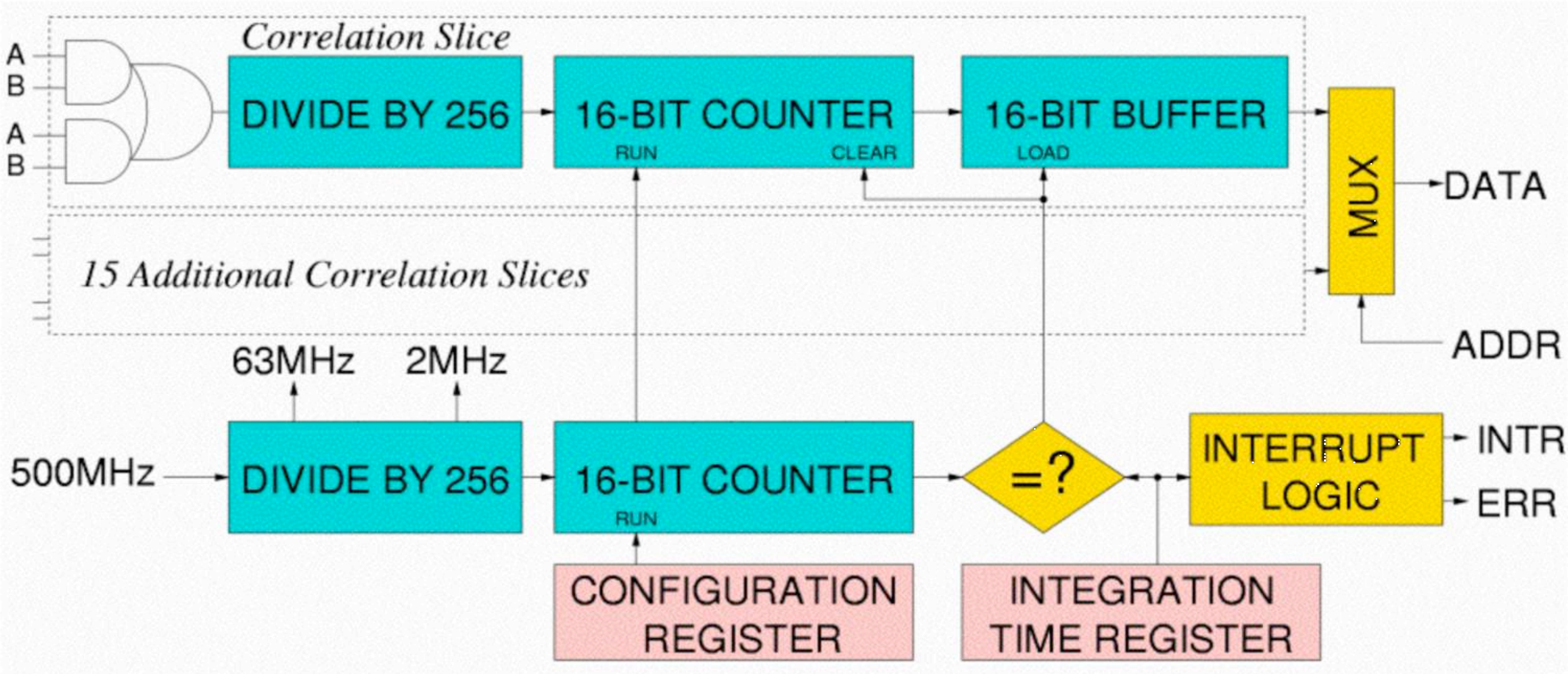
Correlator

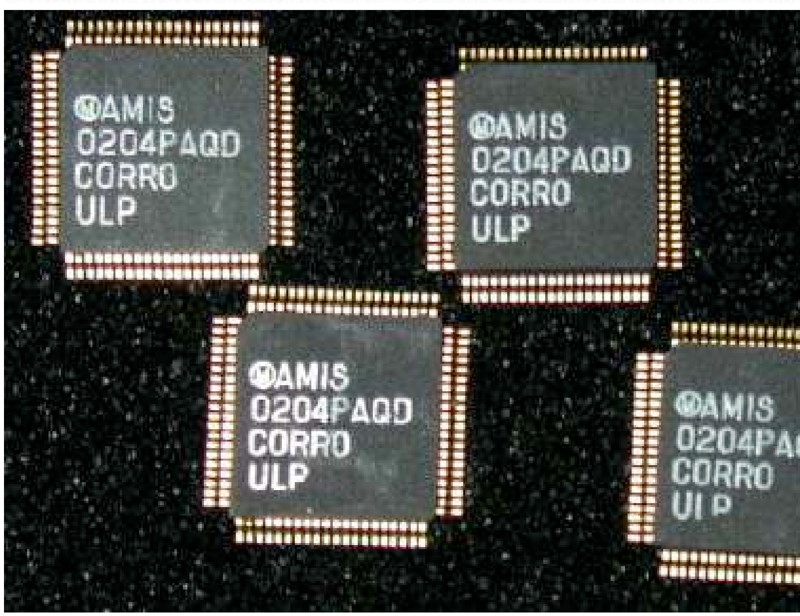
- Performs the multiply and accumulate (MAC)
- 3-level (1.5-bit) quantization
- Four inputs (AI,AQ,BI,BQ)
- Computes all products (self- and cross-)
  - Histogram counters (self-products)
  - II,IQ,QI, and QQ (cross-products)
- One-cycle buffer and uP interface
- Power dissipation: 3-mW core, 7-mW interface
- Prediction (1-bit MAC is <0.2 mW)

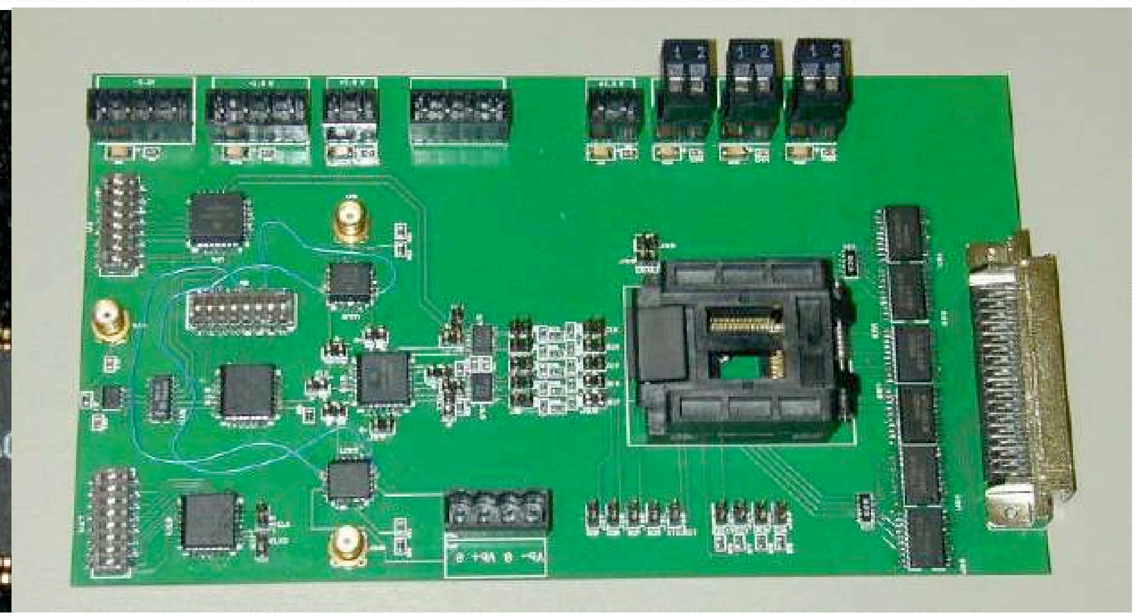
Three level digital correlation



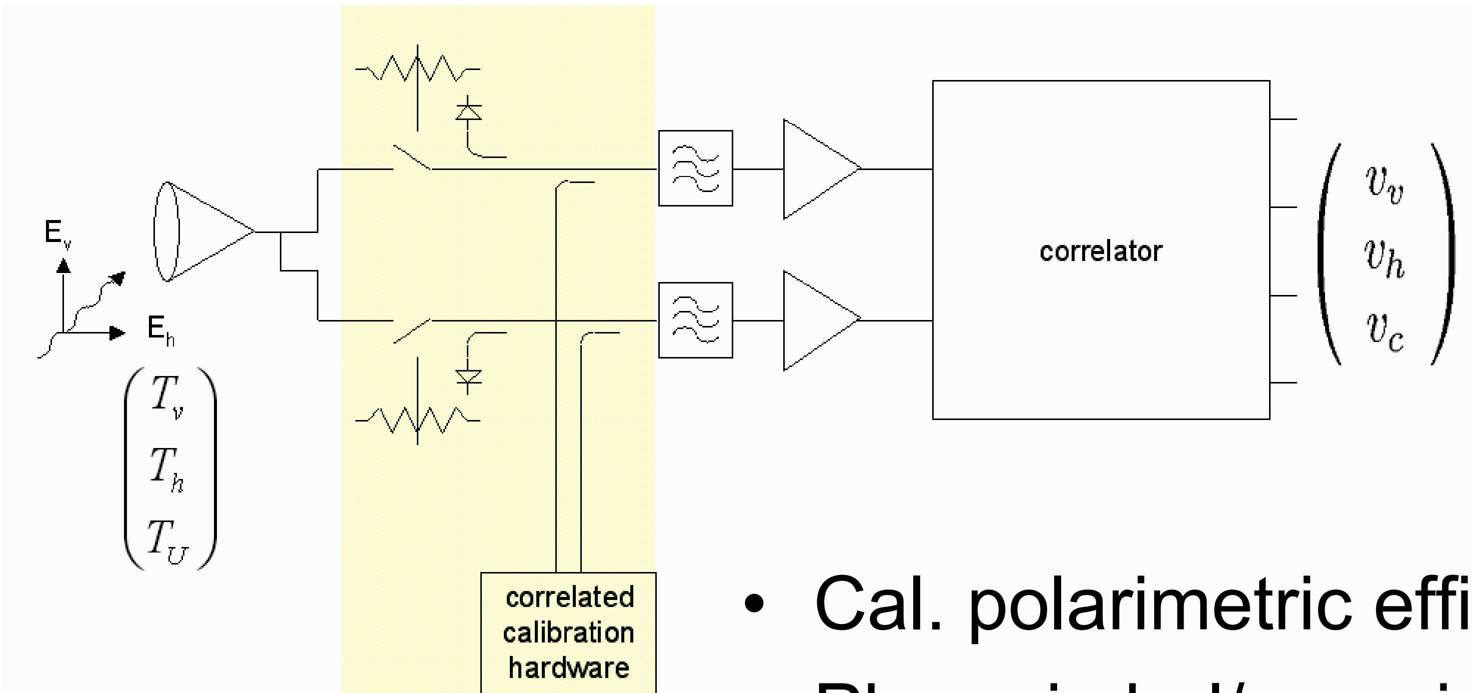
- Inputs v_a and v_b are jointly Gaussian (σ_a^2, σ_b^2, ρ)
- Use expected values to find the input statistics from the output sums.
- $T_U = 2\rho\,(T_{sys,A}\, T_{sys,B})^{1/2}$


Correlation Slice
A
B
A
B
DIVIDE BY 256
16-BIT COUNTER
RUN
CLEAR
16-BIT BUFFER
LOAD
MUX
DATA
15 Additional Correlation Slices
ADDR
63MHz
2MHz
500MHz
DIVIDE BY 256
16-BIT COUNTER
RUN
=?
INTERRUPT LOGIC
INTR
ERR
CONFIGURATION REGISTER
INTEGRATION TIME REGISTER


AMIS
0204PAQD
CORRO
ULP

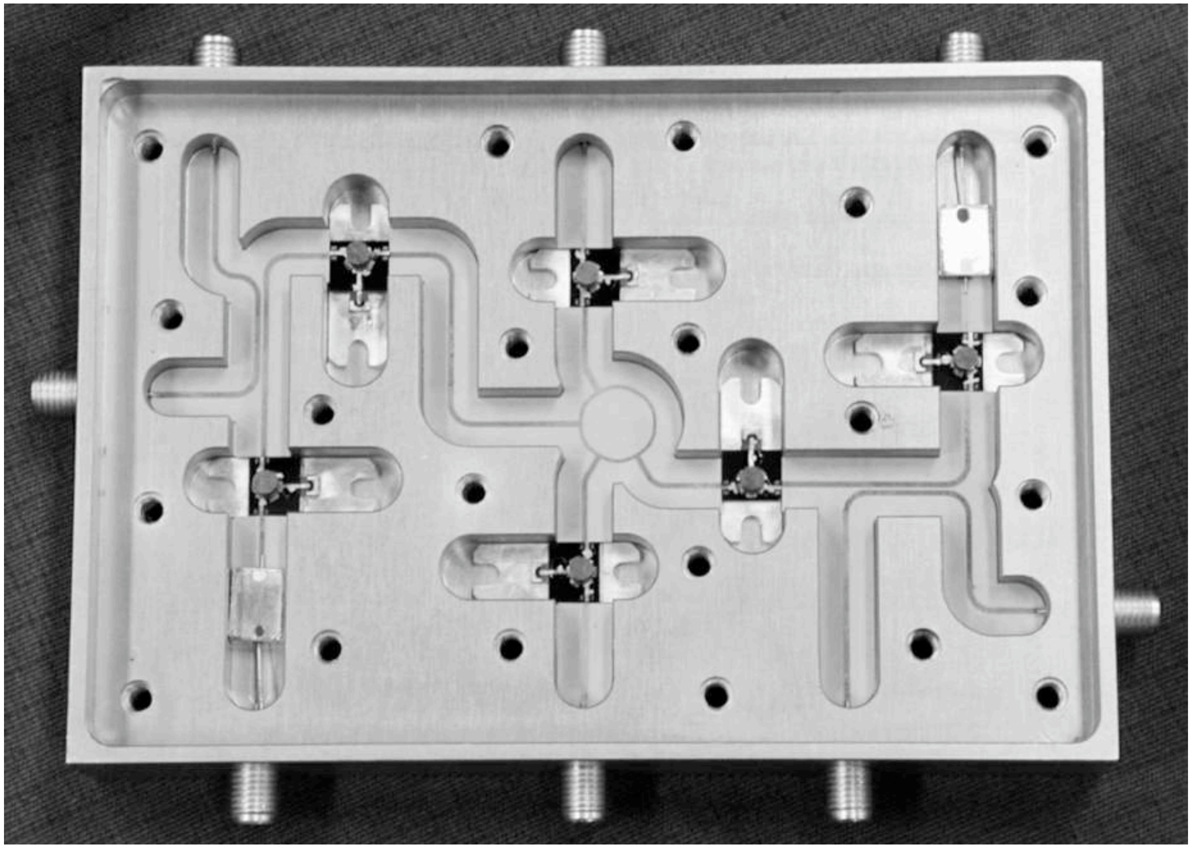


Correlated Noise Source



- Cal. polarimetric efficiency
- Phase imbal/amp ripple
- Part of receiver calibration
- Thermal stability

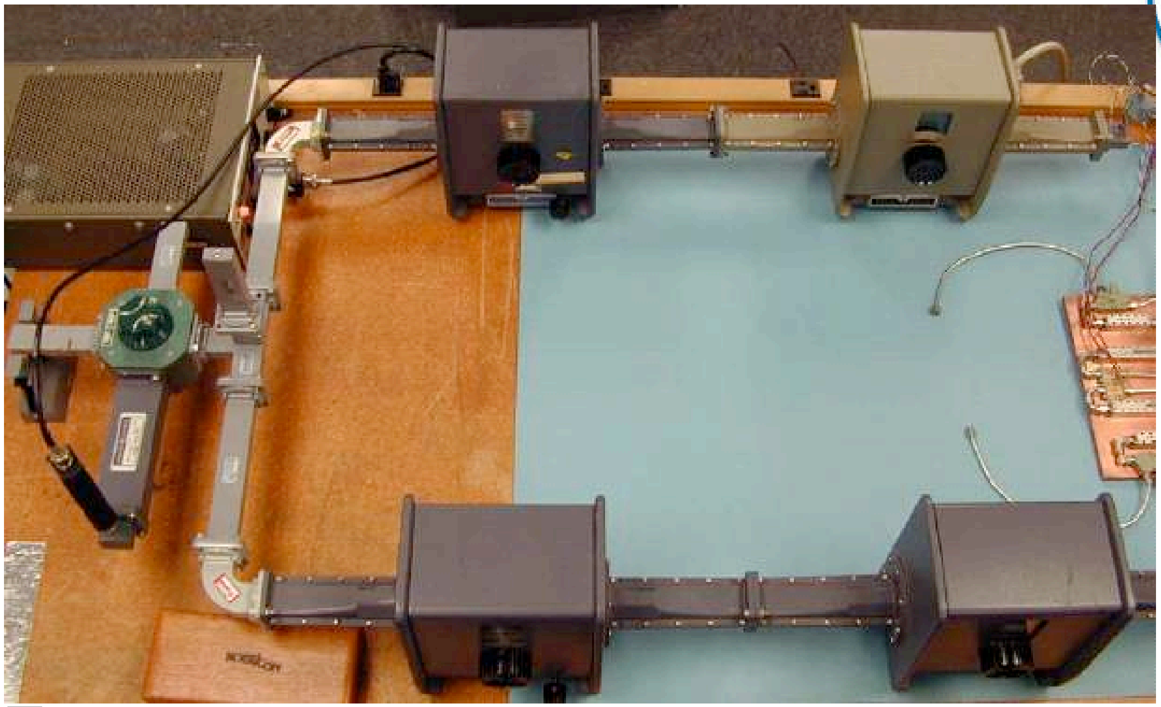
CNS



- <1 degree of phase shift over 30 C temp swing

Waveguide Noise Standard (WGNS)

- Reference input to radiometer

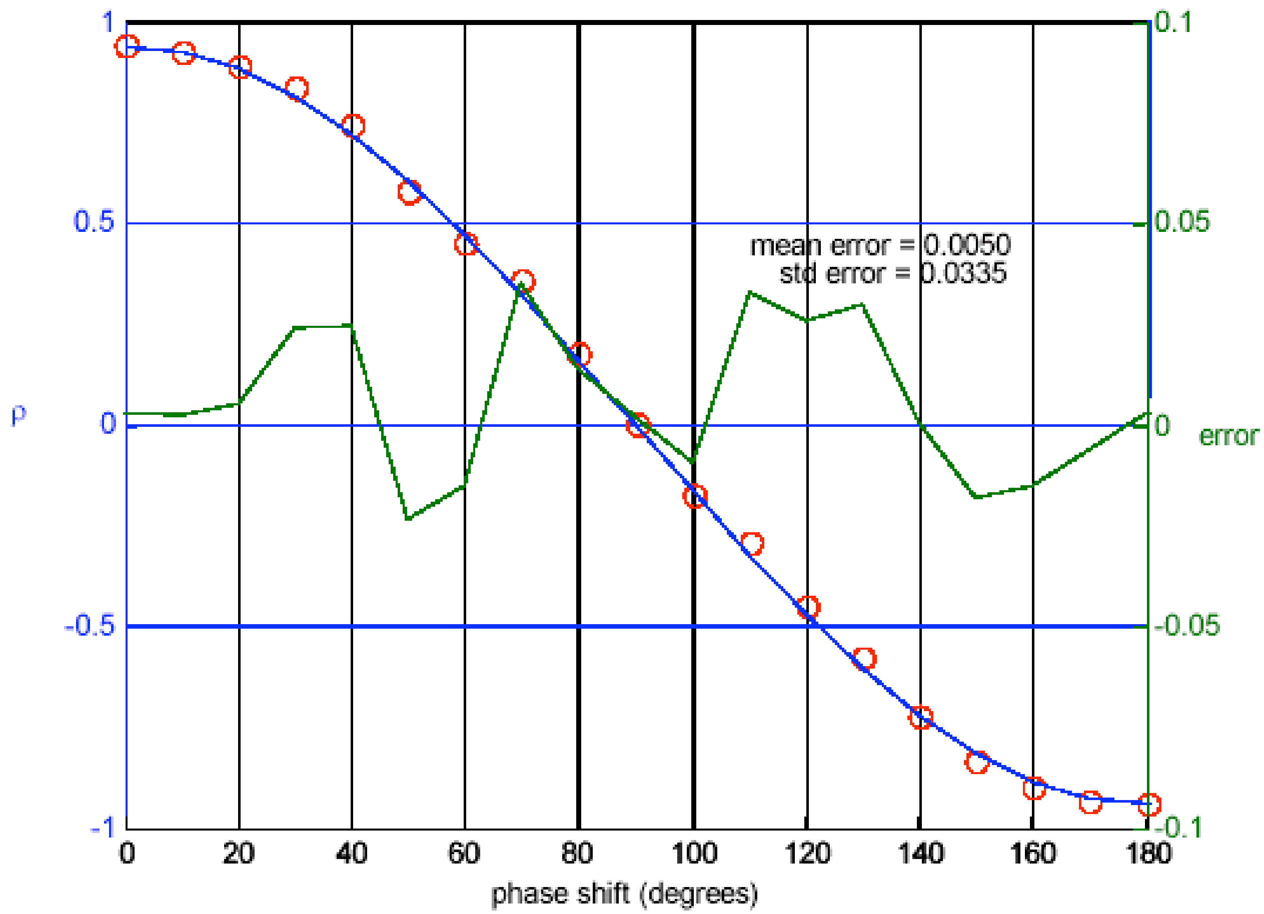


- $\rho_{in,max}$=0.9887
- Up to 14000 K input noise temperature
- 360 degree phase variation available

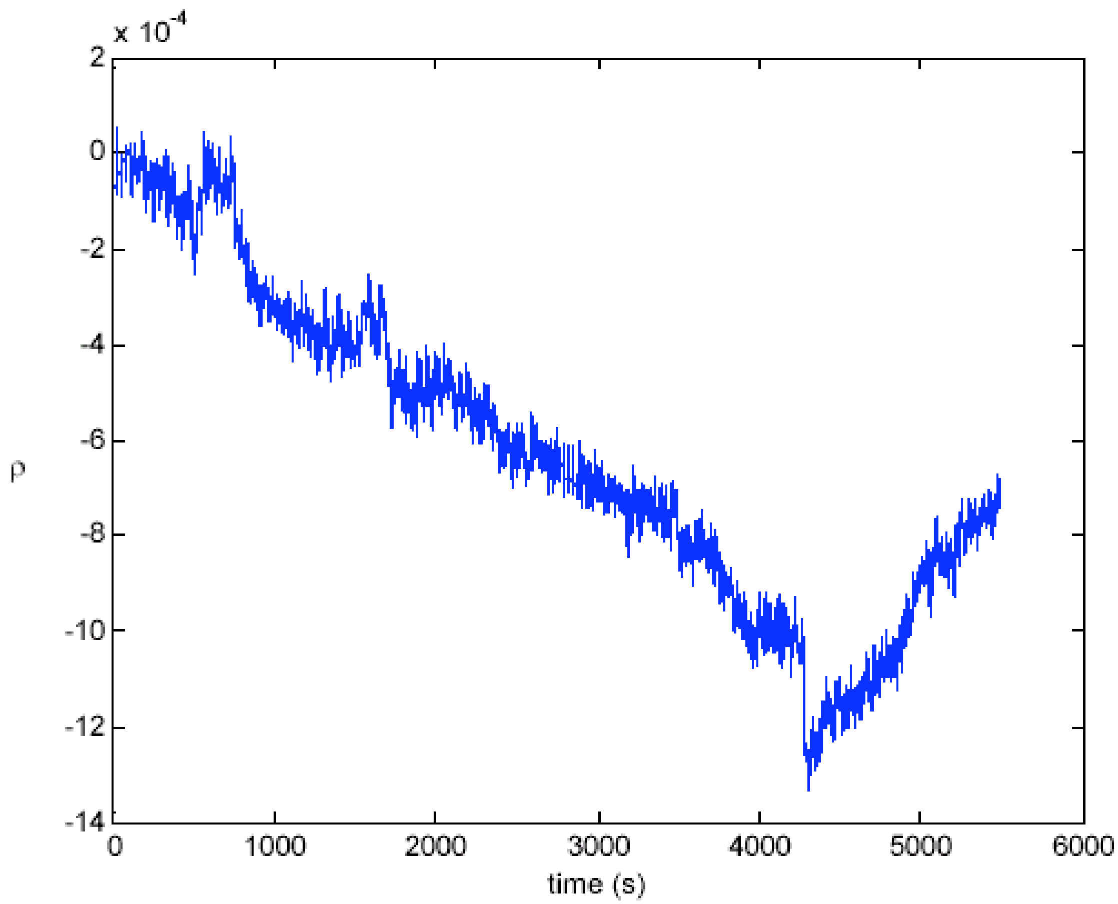
Testing

- WGNS and correlator functional test
- Null offset test
- CNS test

Correlator output variation with WGNS phase difference



Null offset over time



Input signal of 50 mV rms or

-13 dBm (50 Ω)

158 uV or

-43 dBm (50 Ω) correlated noise makes offset = 0.001

CNS testing

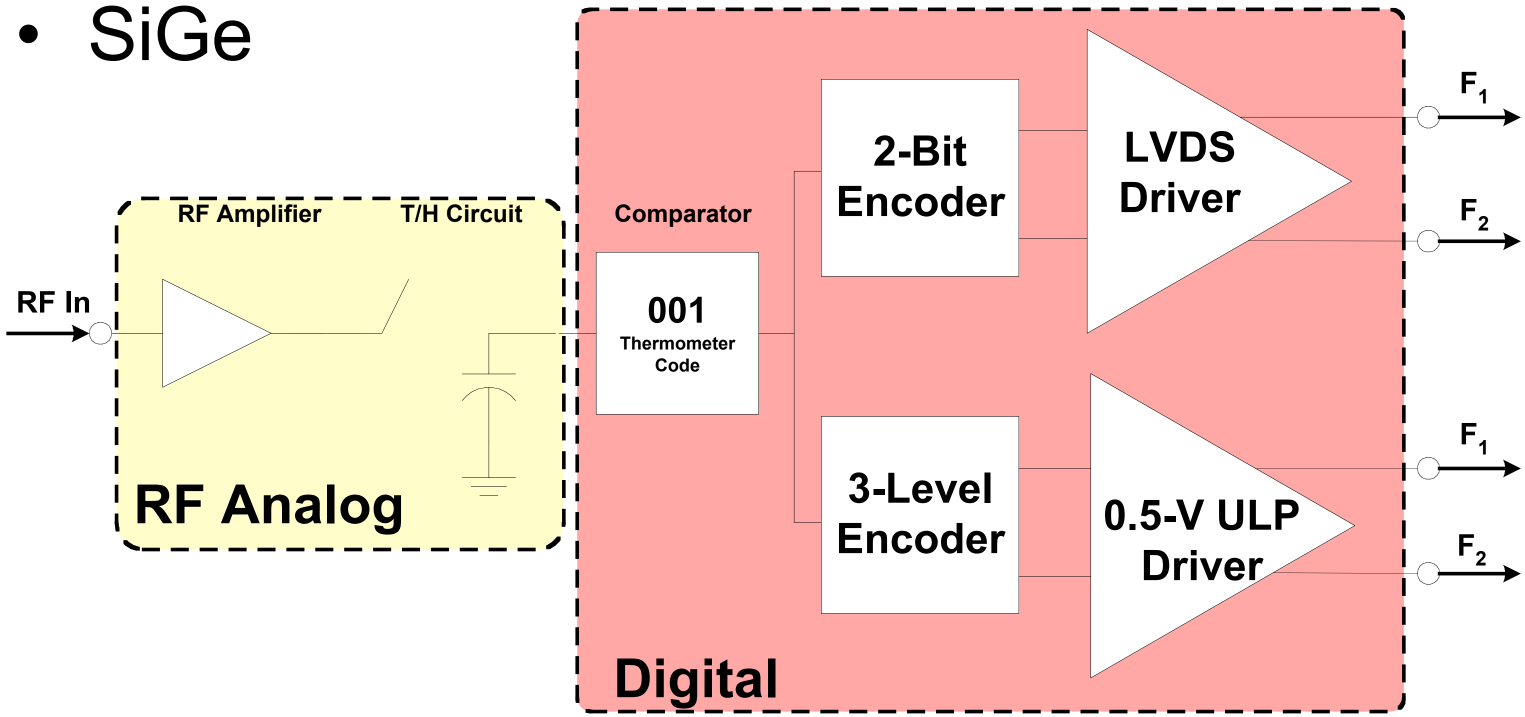
- Plan
  - Measure η using CNS
  - Validate with VNA
- Approach
  - Total power calibration using WGNS
  - Polarimetric calibration using CNS
- Results

Mode	SUM	DIFF
Channel A Temp	1400 K	2033 K
Channel B Temp	1248 K	1874 K
Expected Correlation	+0.6504	-0.7090
Measured Correlation	+0.6496	-0.6989

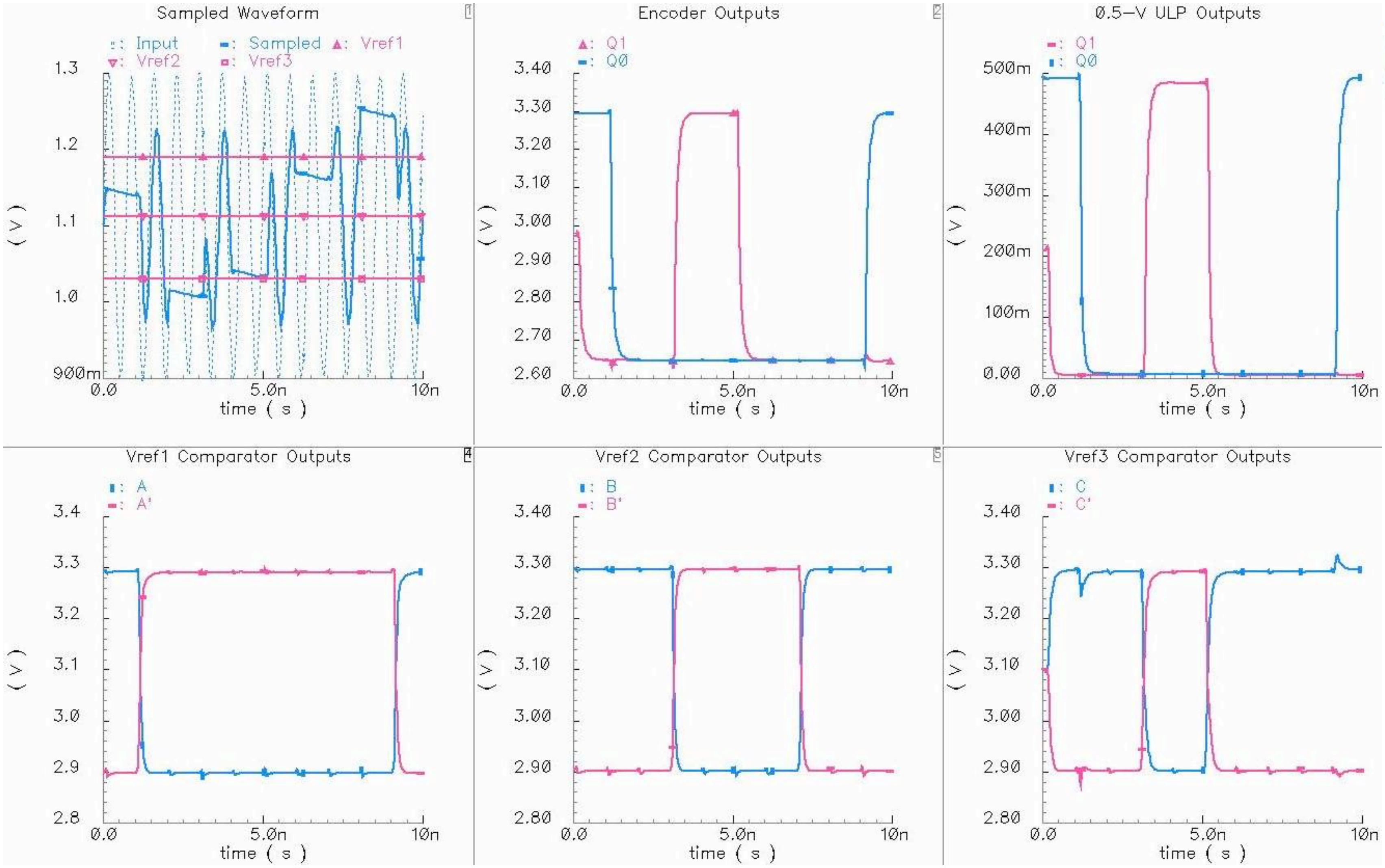
- η_{CNS}=0.9922 η_{VNA}=0.9913 0.1% difference

ADCs

- Low-power ADCs for low resolution apps
- ECL ADCs on test board dissipate ~6 W
- SiGe



Simulated 0.5-V Performance



F_{in} = 1.413 GHz, F_s = 500 MHz

Predicted System Metrics

- Input Bandwidth: > 2.0 GHz
- Sampling Rate: > 1.0 GHz
- Resolution: 2-bit (sign & mag) or 3-level
- Effective-Number-Of-Bits: > 1.6 bits
- Power Supply=3.3V
  - 16 mA for input and core (52 mW)
  - 10 mA for LVDS outputs (32 mW)
  - 24 mA for 0.5-ULP outputs (80 mW)

Discussion

- Power/bandwidth challenge
  - Correlator-based digital receivers
  - Low-power CMOS and SiGe ASICs
- Demonstrated a benchtop (almost) low-power digital microwave polarimeter
- SiGe RF-ADCs out of fab: testing next month
- Will integrate RF-ADCs in Phase III (FY'05)
- Building blocks for a flight digital polarimeter